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Geosynthetic Modeling System-CSC Version 1.00 GM System User's Manual

Computer Sciences Corp., Cincinnati, OH

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16. ABSTRACT

The development of guidance design procedures for the evaluation of geosynthetic materials used in containment systems for landfills, surface impoundments and waste piles has been computerized to increase the speed of calculation of results and to reduce the frequency of human error resulting from manual calculations.

Potential failure modes for each geosynthetic component are established. A design procedure is developed for evaluating each of the potential failure modes. Each design procedure is based on calculation of service conditions in the component under field conditions. A Design Ratio (DR) is then calculated as the ratio of the limiting performance of the component based on laboratory tests to the actual performance calculated for field conditions. Minimum values for Design Ratio are recommended for each design procedure.

Specific geosynthetic material properties are required to determine the DR in each design procedure. A suggested range of values, based on available data, is presented for each material property used. Additionally, a summary of the test procedures used in evaluating each specific material property is provided in the manual. Relevant standards for each test are referenced when available.

This software and users manual should be used with the full report entitled "Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments," PB88-131263/AS.

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GEOSYNTHETIC MODELING SYSTEM

CSC VERSION 1.00

by

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1.0 INTRODUCTION

In cooperation with Robert Hartley of the Land Pollution Control Division (LPCD) of the Hazardous Waste Engineering Research Laboratory (HWERL) in Cincinnati, Ohio, Gregory N. Richardson of Soil and Material Engineers, Inc. and Robert M. Koerner of the Geosynthetic Research Institute at Drexel University, have completed a document entitled "Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments". In an effort to computerize the document's design problems, Craig L. Patterson of Computer Sciences Corporation has completed the Geosynthetic Modeling System (GM System). The objectives of the modeling system are to increase the speed of calculation of results and to reduce the frequency of human error resulting from manual calculations.

The Geosynthetic Modeling System requires a PC Unit with PC DOS, an 8086 Microprocessor with 256 Kbytes of Memory, one 5.25 Inch Diskette Drive with Controller, a Detached Keyboard, and a Printer with an Adapter Board. A Color/Graphics Adapter with suitable Monitor is required to display GM System Graphics. The GM System is written in IBM Advanced Basic 3.00 and is compiled in Microsoft QuickBASIC 3.00. The GM System is distributed on two low density diskettes and requires 3/4 of a Megabyte or 750,000 Bytes of available Disk Space.

2.0 ACCESS TO THE GM SYSTEM

The means by which the user accesses the GM System can vary from system to system. If unable to access the GM System, the user should consult those responsible for maintenance of the microcomputer.

The Geosynthetic Modeling System is distributed on two Double Sided Double Density 5.25 Inch Diskettes (Low Density). To install the GM System, the distribution diskettes must be copied to a fixed disk or a high density diskette with at least 750,000 bytes of available disk space. The GM system is booted by typing "GM".

If the microcomputer has a USEPA Menu System, the GM System can easily be installed in the submenu of programs under the "PROGRAM SELECTION MENU". The user presses function "<F5> MISCELLANEOUS PROGRAMS". The GM System can easily be installed in this submenu under function "<F7> GEOSYNTHETIC MODELING SYSTEM". The user presses <F7> and the GM System appears on the screen.

3.0 THE GM SYSTEM

>>> At any level in the GM System, the user has the option to <<<
>>> press <F10> and <Enter> to escape from the GM System. <<<

If the GM System is "booted" correctly, the "Main Program Menu" appears on the display screen as listed below.

```
GEOSYNTHETIC MODELING SYSTEM
      Main Program Menu
      CSC Version 1.00

0> Return to USEPA Menu

1> Flexible Membrane Liners
     Pseudo Permeability
     DeMinimis Permeability
     Tensile Stress (Liner Weight)
     Tensile Stress (Down Drag)
     Localized Subsidence
     FML Anchorage
     Stability of Soil Cover

2> Leachate Collection And
   Removal Systems
     Transmissivity
     Transmissivity (Operations)
     Transmissivity (Creep)
     Transmissivity-Response Time
     Permittivity

3> Leachate Collection Continued
     Filter-Retention
     Filter-Clogging
     Strength-Sliding
     Strength-Settlement
     Strength-Composite Primary Liner
     Strain-Settlement

4> Ramp and Standpipe Considerations
     Ramp (Sliding)
     Ramp (Drainage)
     Ramp (Wheel Loading)
     Standpipe (Down Drag)
     Standpipe (Puncture of FML)

5> Surface Water Collection And
   Removal Systems
     Transmissivity
     Shear Failure
     Tensile Stress
     FMC Settlement
     FM Wind Lift

              Enter Your Choice Here: _
```

By typing "0", the GM System returns to the EPA Menu or the drive that the system was "booted" on. By typing a number between "1" and "5", a submenu appears corresponding to the selected area of interest. For instance, if the user types "1" to select "Flexible Membrane Liners", a submenu appears as listed below.

```
GEOSYNTHETIC MODELING SYSTEM
Flexible Membrane Liners
CSC Version 1.00

0> Return to Previous Menu
1> Pseudo Permeability
2> DeMinimis Permeability
3> Tensile Stress (Liner Weight)
4> Tensile Stress (Down Drag)
5> Localized Subsidence
6> FML Anchorage
7> Stability of Soil Cover
8> Output Current Results

Enter Your Choice Here: _
```

By typing "0", the GM system returns to the "Main Program Menu". By typing a number between "1" and "7", a design problem appears corresponding to the number selected. For instance, if the user types "1", a design problem for "Pseudo Permeability" is called.

At the beginning of each design problem, a description of the design problem appears on the display screen. A list of "GM System Design Problems" is available in the Appendix. Below the design problem description, a prompt appears followed by a cursor as listed in the example below.

```
Pseudo Permeability:  Calculate the pseudo permeability
of a membrane using the water vapor transmission test.

Enter the Liner Thickness (Mils)----------------------[ 60 ] _

>>> At this level in the GM System, the user has the option   <<<
>>> to press <F9> and <Enter> to escape to the previous menu. <<<
```

Most GM System prompts contain the input variable requested, "Liner Thickness", the units required, "(Mils)", and a default value contained in square brackets, "[60]". The default value is selected by pressing <Enter>. If the default value needs to be changed, the user types in a new value for "Liner Thickness" to the right of the prompt and presses <Enter>.

A "GM System Data Sheet" with input variables has been designed to coincide with the input of data in the GM System and is available in the Appendix. The list of input variables corresponds to the sequential reading of the program. To the left of the input variables, blanks are provided for design problem data. By completing geosynthetic analysis ahead of time and filling in the blanks, the input of data should proceed without difficulty. To the right of each input variable, numbers (#####.##...) identify the maximum size and significant digits of input variables in the GM System.

The user proceeds through the input sequence until one of the following prompts appears on the display screen.

```
Are The Above Entries Correct?  [Y] or N  OR
Is The Above Entry Correct?  [Y] or N
```

If the input values on the screen are correct, the user types "Y" or "y" and <Enter> to display the next sequence of prompts. The default brackets around "[Y]" indicate that pressing <Enter> will also display the next sequence of prompts. If the entries are incorrect, typing "N" or "n" and <Enter> allows the user to enter corrected values on the present screen.

After the last accepted sequence of prompts, the GM System returns to the previous menu, which in this case is the submenu for "Flexible Membrane Liners". Accepted input values for the "Pseudo Permeability" design problem are stored in data files on the drive that the system was "booted" on for future use.

3.1 GM System Results

To obtain calculated results in the submenu for "Flexible Membrane Liners", the user types "8" to "Output Current Results". A prompt appears as listed below.

```
Do You Want to Send the Output to the
Terminal or Lineprinter?  T or [L]
```

Typing "T" or "t" and <Enter> sends the results to the Terminal. Pressing <Enter> or typing any other key and <Enter> sends the results to the Lineprinter. In this case, the data that has been input and the results that have been calculated for "Pseudo Permeability" are output to the selected device. An example of a GM System Output Report is listed below.

```
The Design Problems in the Geosynthetic Modeling System Are
Taken from a Document Entitled 'Geosynthetic Design Guidance
for Hazardous Waste Landfill Cells and Surface Impoundments',
Written by Gregory N. Richardson and Robert M. Koerner.  The
Results Listed Below Pertain to Flexible Membrane Liners.


Pseudo Permeability:  Calculate the pseudo permeability
of a membrane using the water vapor transmission test.

  The Liner Thickness (Mils)-----------------------   60
  The Sample Area (square meters)------------------    0.0030
  The Temperature (degrees Fahrenheit)-------------  105.0
  The Saturation Pressure (millimeters Hg)---------   57.2
  The Humidity Difference (percent)----------------   60.0
  From a Weight Change (grams) vs. Elapsed Time (days) Plot
    The Weight Change (grams)----------------------    0.010
    The Elapsed Time (days)------------------------   20.0
    The Water Vapor Transmissivity (WVT) (g/m^2-d)-    0.1667
  The Permeance (metric perm)----------------------    0.0049
  The Pseudo Permeability (metric perm-Mils)-------    0.2912
  The Pseudo Permeability (cm/sec)-----------------    0.6311E-12

All data entered during this session has been output...
Press <Enter> To Continue...
```

By pressing <Enter>, the GM System returns to the previous menu, which in this case is the submenu for "Flexible Membrane Liners". There is no limit to the number of times a GM System Output Report can be printed or displayed. Any grouping of the seven "Flexible Membrane Liner" design problems can be output at once.

Design problem results will remain current as long as the user does not leave the submenu for "Flexible Membrane Liners". Escaping from the GM System or returning to the "Main Program Menu" stores current input values in data files and clears calculated results from memory. To restore calculated results, select the desired design problem and accept all of the default values provided.

3.2 GM System Regression

Many of the calculated results in the GM System are determined using regression. For instance, the prompt

Is the Trough Circular or Triangular? C or [T]

pertains to settlement trough model curves. Pressing <Enter> or typing "T" or "t" and <Enter> inputs "Settlement Ratio" data in a regression equation to calculate "Uniform Strain" in "Triangular Troughs". While typing "C" or "c" and <Enter> calculates "Uniform Strain" in "Circular Troughs". Similarly, the prompt

Are the Piles Made of Concrete? [Y] or N

pertains to average adhesion/cohesion curves. Pressing <Enter> or typing "Y" or "y" and <Enter> inputs "Cohesion" data in a regression equation to caculate "Adhesion" for "Concrete Piles". Typing "N" or "n" and <Enter> calculates "Adhesion" for "All Piles". Regression is used to calculate the result listed below.

"The Saturation Pressure (millimeters Hg)--------- 57.2"

Previously entered "Temperature" data is input in a regression equation to calculate "Saturation Pressure". Pressures can be calculated from temperature data within the acceptable test range of 60 to 110 degrees Fahrenheit.

3.3 GM System Warning Messages

The GM System contains warning messages for material properties out of commonly observed ranges. For instance, if the calculated "Water Vapor Transmissivity" in the design problem for "Pseudo Permeability" is greater than 1 g/m^2-day during input, the PC beeps and a warning message appears as illustrated below.

Warning! Water Vapor Transmissivity > 1 gram/square meter-day

A system flag ">1" also appears to the left of the results in the GM System Output Report.

>1 Water Vapor Transmissivity (WVT) (g/m^2-d)- 1.1667

If the value is within the commonly observed range, no warning message is displayed during input and no system flags appear in the GM System Output Report.

Warning messages and system flags appear with unacceptable Design Ratios also. For instance, when the calculated Design Ratio for FML "Tensile Stress" is less than 10, the PC beeps and a warning message appears during input as illustrated below.

Warning! Design Ratio < 10

A system flag "<10" also appears to the left of the results in the GM System Output Report.

<10 Design Ratio (A Minimum of 10)---------- 8.01

A system flag "OK" appears if the Design Ratio is acceptable.

OK Design Ratio (A Minimum of 10)---------- 10.00

These warning messages and system flags do not guarantee the calculation and output of infallible results. They are helpful indicators of expected ranges that were observed at the Geosynthetic Research Institute at Drexel University.

A list of "GM System Warning Statements" is available in the Appendix.

3.4 GM System Errors

The GM System is written in a sequential manner, but allows the user to correct errors at convenient places in the system. By following the sequence of the "GM System Data Sheet", data entry should proceed without error. However, the possibility of error is inherent in all data entry, and methods to correct errors are available. The following discussion applies to PC System Unit, input, and output errors.

Many of the design problems in the GM System have graphics which appear on the top half of the display screen. If the PC System does not contain a Color/Graphics Adapter, the GM System graphics appear in Text Mode rather than Graphics Mode. If this is the case, incomprehensible text appears scattered throughout the top half of the screen. In order to see the graphics and correct this error, a Color/Graphics Adapter and suitable Monitor should be connected to the microcomputer. The GM System is written to allow the calculation of results with or without GM System graphics.

Another error results from the input of alphabetic characters in numeric prompts. If a letter of the alphabet is input in a numeric prompt, zero will replace the alphabetic character in GM System calculations. The user can reject the incorrect entries and input numeric values, or press <F9> and <Enter> to escape to the previous menu.

Additional errors result from input values too large for the magnitude of the GM System. If the value is too large for the space allotted in the GM System Output Report, a % sign appears during output. Numbers (#####.##...) are provided in the "GM System Data Sheet" to identify the maximum size and significant digits of input values in the GM System. Calculated results follow similar conventions.

APPENDIX

GM System Design Problems

1> Flexible Membrane Liners

Pseudo Permeability: Calculate the pseudo permeability of a membrane using the water vapor transmission test.

DeMinimis Permeability: Calculate the Factor of Safety based on actual leakage vs. gallons/acre/day.

Tensile Stress (Liner Weight): Evaluate the ability of the FML to support its own weight on the side slopes.

Tensile Stress (Down Drag): Calculate the FML stress generated during construction of the interior cell adjacent to the sidewalls of a facility.

Localized Subsidence: Evaluate the strains induced in the FML by localized subsidence.

FML Anchorage: Calculate the anchor capacity for the FML placed in various anchorage configurations.

Stability of Soil Cover: Verify that the soil cover will not slide on FML. Also verify the anchor capacity and stress in FML.

2> Leachate Collection And Removal Systems

Transmissivity: Verify that the leachate collection/removal system provides adequate planar flow.

Transmissivity (Operations): Verify that the primary LCR will handle surface water during operation of the facility.

Transmissivity (Creep): Determine the impact of long-term creep on the transmissivity of the synthetic LCR.

Transmissivity-Response Time: Calculate the minimum time required for leachate entering the LCR to be detected at the sump.

Permittivity: Verify that a geotextile will allow leachate to flow through it.

3> Leachate Collection And Removal Systems

Filter-Retention: Compare grain size distribution of the retained soil to the opening size of the geotextile to verify retention of particles.

Filter-Clogging: Evaluate the influence of obtained soil particles on the permittivity of a geotextile.

Strength-Sliding: Evaluate the stresses generated during construction of interior shells adjacent to the sidewalls of the facility.

3> Leachate Collection And Removal Systems (Continued)

Strength-Settlement: Determine the ability of the LCR to resist down-drag forces resulting from the subsidence of the contained waste.

Strength-Composite Primary Liner: Verify that the SLCR can support the wt. of the composite primary liner system prior to placement of the waste.

Strain-Settlement: Evaluate the strains produced in the LCR by settlement of the waste.

4> Ramp and Standpipe Considerations

Ramp (Sliding): Verify that the ramp sub-base is stable under the load.

Ramp (Drainage): Verify that the ramp will adequately drain surface water from the roadway.

Ramp (Wheel Loading): Verify that the wheel loading will not damage the FML.

Standpipe (Down Drag): Evaluate the potential for down-drag forces acting on the standpipe and compare coatings for reduction of these forces.

Standpipe (Puncture of FML): Verify that down-drag induced settlement of the standpipe will not cause failure of the underlying LCR.

5> Surface Water Collection And Removal Systems

Transmissivity: Verify the capacity of the surface water collection and removal system to maintain 1 foot of head with the given cap geometry.

Shear Failure: Evaluate the sliding stability of the cover soil and the design ratio against the shear failure of the SWCR system.

Tensile Stress: Evaluate the ability of the SWCR system to resist tensile forces resulting from imbalance in shear capacity.

Settlement: Verify the ability of the FMC to survive settlement resulting from long-term waste compression settlement.

Wind Lift: Calculate the required sandbag spacing for FML/FMC panels during placement.

GM System Data Sheet

1> Flexible Membrane Liners
   1> Pseudo Permeability

_____ Liner Thickness (Mils)----------#####.
_____ Sample Area (square meters)----------#####.####
_____ Temperature (degrees Fahrenheit)----------#####.#
_____ Humidity Difference (percent)----------#####.#
      Plot Weight Change (grams) vs. Elapsed Time (days)
_____   Weight Change (grams)----------#####.###
_____   Elapsed Time (days)----------#####.#

1> Flexible Membrane Liners
   2> DeMinimis Permeability

_____ Liner Thickness (Mils)----------#####.
_____ Sample Area (square meters)----------#####.####
_____ Temperature (degrees Fahrenheit)----------#####.#
_____ Humidity Difference (percent)----------#####.#
      Plot Weight Change (grams) vs. Elapsed Time (days)
_____   Weight Change (grams)----------#####.###
_____   Elapsed Time (days)----------#####.#
_____ Leachate Headloss <=12 (inches)----------#####.##
_____ Area (square inches)----------#####.##

1> Flexible Membrane Liners
   3> Tensile Stress (Liner Weight)

_____ Liner Thickness (Mils)----------#####.
_____ FML Specific Gravity----------#####.####
_____ Friction Angle--FML to LCR (degrees)---------#####.#
_____ Depth of Landfill (feet)----------#####.##
_____ Slope Angle (degrees)----------#####.#
      Plot Stress (pounds/square inch) vs. Strain (percent)
_____   FML Yield Stress (pounds/square inch)------#####.##

1> Flexible Membrane Liners
   4> Tensile Stress (Down Drag)

_____ Cell Thickness (feet)----------#####.##
_____ Unit Weight of Waste (pounds/cubic foot)-----#####.#
_____ Slope Angle (degrees)----------#####.#
_____ Friction Angle--PLCR to PFML (degrees)-------#####.#
_____ Friction Angle--PFML to SLCR (degrees)-------#####.#
_____ Liner Thickness (Mils)----------#####.
      Plot Stress (pounds/square inch) vs. Strain (percent)
_____   FML Yield Stress (pounds/square inch)------#####.##

1> Flexible Membrane Liners
5> Localized Subsidence

_____ Liner Thickness (Mils)----------#####.
_____ Tensile Strength (pounds/square inch)--------#####.##
_____ Friction Angle--Soil to FML (degrees)--------#####.#
_____ Normal Stress (kilopounds/square foot)-------#####.##
Width of Excavation + 45 degree Extension Through Support Layer
_____ Width of Subsidence (inches)---------------#####.##
Minimum of Approximately 20 percent of the Depth of Excavation
_____ Depth of Subsidence (inches)---------------#####.##
_____ Is the Trough Circular or Triangular? C or [T]

1> Flexible Membrane Liners
6> FML Anchorage

_____ Slope Angle (degrees)----------#####.#
_____ Embedment Length (feet)----------#####.##
_____ Depth of Soil Cover (feet)----------#####.##
_____ Design Ratio (A Minimum of 1.5)----------#####.##
_____ Friction Angle--Soil (degrees)----------#####.#
_____ Friction Angle--Soil to FML (degrees)--------#####.#
_____ Unit Weight of Soil (pounds/cubic foot)------#####.#
_____ Length of V Trench (feet)----------#####.##
_____ Depth of V Trench (feet)----------#####.##
_____ Slope Angle of the V Trench (degrees)--------#####.#
_____ Anchor Depth (feet)----------#####.##
Find the Ka and Kp of the Concrete Anchor
_____ Active Stress Ratio Ka----------#####.####
_____ Passive Stress Ratio Kp----------#####.####
Find the Ko of the Anchor Trench
_____ Lateral Stress Ratio Ko----------#####.####

1> Flexible Membrane Liners
7> Stability of Soil Cover

_____ Saturated Unit Weight (pounds/cu. foot)------#####.#
_____ Friction Angle--Soil to FML (degrees)--------#####.#
_____ Friction Angle--FML to LCR (degrees)---------#####.#
_____ Thickness of the FML (Mils)----------#####.
_____ FML Yield Stress (pounds/square inch)--------#####.##
_____ Height of the Neutral Block (feet)----------#####.##
_____ Length of the Neutral Block (feet)----------#####.##
_____ Height at the Top of the Soil Cover (ft)-----#####.##
_____ Slope Length (feet)----------#####.##
_____ Slope Angle (degrees)----------#####.#

2> Leachate Collection And Removal Systems
1> Transmissivity

_____ Slope Angle (degrees)----------#####.#
_____ Slope Length (feet)----------#####.##
_____ Leachate Inflow Rate (feet/day)----------#####.##
_____ Landfill Height (feet)----------#####.##
_____ Unit Weight of Waste (pounds/cubic foot)-----#####.#
Plot Transmissivity (square meters/sec) vs. Hydr. Gradient
_____ Lab Transmissivity (sq meters/second)------#.####E+##

2> Leachate Collection And Removal Systems
2> Transmissivity (Operations)

_____ Rainfall Intensity (inches/hour)----------#####.#
_____ Watershed Area (acres)----------#####.#
_____ Coefficient of Runoff----------#####.#
_____ Length of Effective LCR in Watershed (ft)----#####.##
_____ Unit Weight of Waste (pounds/cubic foot)-----#####.#
_____ Flow Length (feet)----------#####.##
_____ Headloss (feet)----------#####.##
_____ Width of the LCR (feet)----------#####.##
Plot Transmissivity (square meters/sec) vs. Hydr. Gradient
_____ Lab Transmissivity (sq meters/second)------#####.####

2> Leachate Collection And Removal Systems
3> Transmissivity (Creep)

_____ Landfill Height (feet)----------#####.##
_____ Unit Weight of Waste (pounds/cubic foot)-----#####.#
_____ Slope Length (feet)----------#####.##
_____ Slope Angle (degrees)----------#####.#
Plot Transmissivity (square meters/second) vs. Time (hours)
_____ Long-Term Transmissivity (sq m/sec)--------#.####E+##

2> Leachate Collection And Removal Systems
4> Transmissivity-Response Time

_____ Sidewall Transmissivity (sq m/sec)----------#.####E+##
_____ Slope Length of the Sidewall (feet)----------#####.##
_____ Sidewall Hydraulic Gradient----------#####.####
_____ Thickness of the Synthetic LCR (cm)----------#####.##
_____ Porosity of the Synthetic LCR----------#####.##
_____ Hydr. Conductivity of Bottom LCR (cm/sec)----#####.####
_____ Dry Unit Weight of the Bottom LCR (pcf)------#####.#
_____ Specific Gravity of the Bottom LCR----------#####.##
_____ Max Flow Length to Collector Pipe (feet)-----#####.##
_____ Hydraulic Gradient in the Bottom LCR---------#####.####

2> Leachate Collection And Removal Systems
5> Permittivity

_____ Leachate Inflow Rate (feet/day)----------#####.##
Plot Flow Rate (cu mm/sec) vs. Head (mm)
_____ Geotextile Flow Rate (cu mm/sec)----------#####.##
_____ Geotextile Head (mm)----------#####.##
_____ Geotextile Area (square mm)----------#####.##

3> Leachate Collection And Removal Systems
1> Filter-Retention

_____ Apparent Opening Size of Geotextile (mm)-----#####.####
_____ Soil Passing a #200 (0.074 mm) Sieve (%)-----#####.##
Plot Percent Finer by Weight vs. Grain Size in Millimeters
_____ Grain Size of 85% Finer by Weight (mm)-----#####.####
_____ Grain Size of 60% Finer by Weight (mm)-----#####.####
_____ Grain Size of 50% Finer by Weight (mm)-----#####.####
_____ Grain Size of 15% Finer by Weight (mm)-----#####.####
_____ Grain Size of 10% Finer by Weight (mm)-----#####.####

3> Leachate Collection And Removal Systems
2> Filter-Clogging

_____ Change in Height at 2 Inches (inches)--------#####.##
_____ Change in Height at 1 Inch + GT (inches)-----#####.##
_____ Change in Thickness at 2 Inches (inches)-----#####.##
_____ Change in Thickness at 1 Inch + GT (inches)--#####.##

3> Leachate Collection And Removal Systems
3> Strength-Sliding

_____ Cell Thickness (feet)----------#####.##
_____ Unit Weight of Waste (pounds/cubic foot)-----#####.#
_____ Slope Angle (degrees)----------#####.#
_____ Friction Angle--LCR to Waste (degrees)-------#####.#
_____ Friction Angle--LCR to FML (degrees)---------#####.#
Plot Tension (pounds/foot) vs. Strain (percent)
_____ Width of the Lab Sample (inches)----------#####.##
_____ Maximum Laboratory Tension (pounds/foot)---#####.##

3> Leachate Collection And Removal Systems
4> Strength-Settlement

_____ Waste Height (feet)----------#####.##
_____ Unit Weight of Waste (pounds/cubic foot)-----#####.#
_____ Slope Angle (degrees)----------#####.#
_____ Friction Angle--LCR to Waste (degrees)-------#####.#
_____ Friction Angle--LCR to FML (degrees)---------#####.#
Plot Tension (pounds/foot) vs. Strain (percent)
_____ Width of the Lab Sample (inches)----------#####.##
_____ Maximum Laboratory Tension (pounds/foot)---#####.##

3> Leachate Collection And Removal Systems
5> Strength-Composite Primary Liner

_____ Unit Weight of Soil Liner (pounds/cu ft)-----#####.#
_____ Thickness of the Soil Liner (inches)---------#####.##
_____ Slope Angle (degrees)-----------------------#####.#
_____ Friction Angle--SLCR to Soil (degrees)-------#####.#
_____ Friction Angle--SLCR to SFML (degrees)-------#####.#
_____ Friction Angle--SFML to Soil (degrees)-------#####.#
_____ Cell Depth (feet)---------------------------#####.##
Plot Tension (pounds/foot) vs. Strain (percent)
_____ Width of the Lab Sample (inches)-----------#####.##
_____ Maximum Laboratory Tension (pounds/foot)---#####.##

3> Leachate Collection And Removal Systems
6> Strain-Settlement

_____ Slope Angle of Sideslope (degrees)----------#####.#
_____ Maximum Waste Settlement (inches)-----------#####.##
Plot Tension (pounds/foot) vs. Strain (percent)
_____ Yield Strain of the LCR Synthetic (%)------#####.##
_____ Ultimate Strain of the LCR Synthetic (%)---#####.##
_____ Length of Exposed LCR (feet)----------------#####.##

4> Ramp and Standpipe Considerations
1> Ramp (Sliding)

_____ Equipment Weight (tons)---------------------#####.##
_____ Friction Angle--Soil to LCR (degrees)-------#####.#
_____ Friction Angle--Soil to FML (degrees)-------#####.#
_____ Friction Angle--FML to LCR (degrees)--------#####.#
_____ Ramp Width (feet)---------------------------#####.#
_____ Ramp Length (feet)--------------------------#####.##
_____ Ramp Thickness (inches)---------------------#####.##
_____ Ramp Slope Angle (degrees)------------------#####.#
_____ Unit Weight of the Sub-Base (lbs/cu ft)-----#####.#
_____ Minimum Interface Adhesion (pounds/sq ft)---#####.##

4> Ramp and Standpipe Considerations
2> Ramp (Drainage)

_____ Ramp Width (feet)---------------------------#####.##
_____ Ramp Thickness (inches)---------------------#####.##
_____ Ramp Slope Angle (degrees)------------------#####.#
_____ Coefficient of Rainfall---------------------#####.#
_____ Rainfall Intensity (inches/hour)------------#####.#
_____ Area of the Watershed (acres)---------------#####.#
_____ Transmissivity of the LCR (sq meters/second)-#.####E+##
_____ Permeability of the Sub-Base (cm/second)-----#.####E+##

```
4> Ramp and Standpipe Considerations
   3> Ramp (Wheel Loading)
_________ Weight of the Vehicle (tons)-----------------#####.##
_________ Number of Vehicle Wheels---------------------#####.
_________ Ground Contact Pressure (pounds/sq inch)-----#####.##
_________ Ramp Thickness (inches)----------------------#####.##
_________ Roadway Sub-Base Friction Angle (degrees)----#####.#
          Plot Compressive Stress (psi) vs. Deflection (inches)
_________   Compressive Stress at 10% Penetration (psi)#####.##


4> Ramp and Standpipe Considerations
   4> Standpipe (Down Drag)

_________ Diameter of the Standpipe (inches)-----------#####.##
_________ Diameter of the Standpipe Footer (inches)----#####.##
_________ Depth of the Standpipe (feet)----------------#####.##
_________ Cohesion of the Clay Backfill (lbs/sq ft)----#####.##
_________ Are the Piles Made of Concrete?  [Y] or N


4> Ramp and Standpipe Considerations
   5> Standpipe (Puncture of FML)

_________ Diameter of the Standpipe (inches)-----------#####.##
_________ Diameter of the Standpipe Footer (inches)----#####.##
_________ Depth of the Standpipe (feet)----------------#####.##
_________ Cohesion of the Clay Backfill (lbs/sq ft)----#####.##
_________ Are the Piles Made of Concrete?  [Y] or N
_________ Initial Void Ratio of the Subgrade-----------#####.####
_________ Subgrade Cohesion (pounds/square foot)-------#####.##
_________ Poisson's Ratio for the Subgrade-------------#####.####
_________ Compression Index of the Subgrade------------#####.####
_________ Yield Stress of the FML (pounds/sq inch)-----#####.##
_________ FML Thickness (Mils)-------------------------#####.
_________ FML Strain at Yield (percent)----------------#####.##
_________ Thickness of the Clay Liner (inches)---------#####.##
_________ Unit Weight of the Waste (lbs/cu ft)---------#####.#
_________ Unit Weight of the Clay (lbs/cu ft)----------#####.#
_________ Depth of Excavation (feet)-------------------#####.##
          Plot Settlement (inches) vs. Poisson's Ratio/Radius
_________   Length (L) from Settlement Profile (inches)#####.## AND/OR
_________ Friction Angle--FML to Soil (degrees)--------#####.#


5> Surface Water Collection And Removal Systems
   1> Transmissivity

_________ Height of the Soil Cover (feet)--------------#####.##
_________ Unit Weight of the Cover Soil (lbs/cu ft)----#####.#
_________ Slope Angle (degrees)------------------------#####.#
_________ Spacing of Collector Pipes (feet)-------------#####.##
_________ Surface Water Inflow Rate (ft^3/ft^2/day)----#####.##
          Plot Transmissivity (square meters/sec) vs. Hydr. Gradient
_________   Lab Transmissivity (sq meters/second)------#####.####
```

5> Surface Water Collection And Removal Systems
2> Shear Failure

_____ Friction Angle--Soil to SWCR (degrees)-------#####.#
_____ Friction Angle--SWCR to FMC (degrees)--------#####.#
_____ Slope Angle (degrees)-----------------------#####.#
_____ Depth of the Soil Cover (feet)---------------#####.##
_____ Unit Weight of the Cover Soil (lbs/cu ft)----#####.#
_____ Shear Strength of the SWCR (lbs/sq inch)-----#####.##

5> Surface Water Collection And Removal Systems
3> Tensile Stress

_____ Friction Angle--Soil to SWCR (degrees)-------#####.#
_____ Friction Angle--SWCR to FMC (degrees)--------#####.#
_____ Slope Angle (degrees)-----------------------#####.#
_____ Depth of the Soil Cover (feet)---------------#####.##
_____ Unit Weight of the Cover Soil (lbs/cu ft)----#####.#
_____ Tensile Strength of the SWCR (lbs/in)--------#####.##
_____ Slope Length (feet)-------------------------#####.##

5> Surface Water Collection And Removal Systems
4> FMC Settlement

_____ Minimum Width of Cell (feet)-----------------#####.##
_____ Depth of Waste (feet)------------------------#####.##
_____ Percent Settlement (A Minimum of 5)----------#####.##
_____ Is the Trough Circular or Triangular? C or [T]
_____ Plot Uniaxial Load (pounds/inch) vs. Strain (percent)
_____ FMC Strain at Yield (percent)--------------#####.##
_____ FMC Strain at Rupture (percent)------------#####.##

5> Surface Water Collection And Removal Systems
5> FM Wind Lift

_____ Annual Extreme Windspeed (miles/hour)--------#####.##
_____ Depth of the FML Below Ground (feet)---------#####.##
_____ Elevation at Ground Level (feet)-------------#####.##
_____ Elevation of the FM Above Ground (feet)------#####.##
_____ Weight of Each Sandbag (pounds)--------------#####.##
_____ Spacing of Sandbags (1 per # of sq ft)-------#####.##
_____ Plot Pressure (psf) vs. Height (feet) at Maximum Wind Speed
_____ Uplift Pressure at #### Feet (psf)---------#####
_____ Uplift Pressure at #### Feet (psf)---------#####
_____ Uplift Pressure at #### Feet (psf)---------#####

GM System Warning Statements

1> Flexible Membrane Liners

```
"The Water Vapor Transmissivity (WVT) (g/m^2-day)----:
"WARNING!  Water Vapor Transmissivity > 1 gram/square meter-day"

"The Water Vapor Transmissivity (WVT) (g/m^2-day)----:
"WARNING!  Water Vapor Transmissivity > 1 gram/square meter-day"

"Enter Maximum Leachate Head on Liner (inches)-------[
"WARNING!  Maximum Leachate Head > 12 inches"

"The Design Ratio (A Minimum of 2)-------------------:
"WARNING!  Design Ratio < 2"

"Enter the Liner Thickness (Mils)--------------------[
"WARNING!  Liner Thickness > 120 Mils"
"WARNING!  Liner Thickness < 30 Mils"

"Enter the FML Specific Gravity----------------------[
"WARNING!  Specific Gravity > 1.4"
"WARNING!  Specific Gravity < 0.92"

"Enter the Friction Angle--FML to LCR (degrees)------[
"WARNING!  Friction Angle > 45 degrees"
"WARNING!  Friction Angle < 10 degrees"

"Enter the FML Yield Stress (pounds/square inch)-----[
"WARNING!  Yield Stress > 5000 pounds/square inch"
"WARNING!  Yield Stress < 1000 pounds/square inch"

"The Design Ratio (A Minimum of 10)------------------:
"WARNING!  Design Ratio < 10"

"Enter the Friction Angle--PLCR to PFML (degrees)----[
"WARNING!  Friction Angle > 30 degrees"
"WARNING!  Friction Angle < 10 degrees"

"Enter the Friction Angle--PFML to SLCR (degrees)----[
"WARNING!  Friction Angle > 30 degrees"
"WARNING!  Friction Angle < 10 degrees"

"Enter the FML Yield Stress (pounds/square inch)-----[
"WARNING!  Yield Stress > 5000 pounds/square inch"
"WARNING!  Yield Stress < 1000 pounds/square inch"

"The Design Ratio (A Minimum of 5)-------------------:
"WARNING!  Design Ratio < 5"

"Enter the Design Ratio (A Minimum of 1.5)-----------[
"WARNING!  Design Ratio < 1.5"
```

```
"Enter the Friction Angle--Soil (degrees)------------[
"WARNING!  Friction Angle > 38 degrees"
"WARNING!  Friction Angle < 25 degrees"

"Enter the Friction Angle--Soil to FML (degrees)-----[
"WARNING!  Friction Angle > 20 degrees"
"WARNING!  Friction Angle < 12 degrees"

"Enter the Friction Angle--Soil to FML (degrees)-----[
"WARNING!  Friction Angle > 20 degrees"
"WARNING!  Friction Angle < 10 degrees"

"Enter the Friction Angle--FML to LCR (degrees)------[
"WARNING!  Friction Angle > 15 degrees"
"WARNING!  Friction Angle < 8 degrees"

"Enter the FML Yield Stress (pounds/square inch)-----[
"WARNING!  Yield Stress > 2200 pounds/square inch"
"WARNING!  Yield Stress < 1000 pounds/square inch"

"The Design Ratio (A Minimum of 1.2)-----------------:
"WARNING!  Design Ratio < 1.2"


2> Leachate Collection and Removal Systems

"The Transmissivity (square meters/second)-----------:
"WARNING!  Transmissivity < 3E-5 square meters/second"

"The Design Ratio (A Minimum of 10)------------------:
"WARNING!  Design Ratio < 10"

"The MTG Design Ratio (A Minimum of 10)--------------:
"WARNING!  MTG Design Ratio < 10"

"The Transmissivity (square meters/second)-----------:
"WARNING!  Transmissivity < 3E-5 square meters/second"

"The Design Ratio (A Minimum of 3)-------------------:
"WARNING!  Design Ratio < 3"

"Enter the Long-Term Transmissivity (sq m/sec)-------[
"WARNING!  Transmissivity < 3E-5 square meters/second"

"The Design Ratio (A Minimum of 5)-------------------:
"WARNING!  Design Ratio < 5"

"Enter the Sidewall Transmissivity (sq m/sec)--------[
"WARNING!  Transmissivity < 3E-5 square meters/second"

"Enter the Porosity of the Synthetic LCR-------------[
"WARNING!  Porosity > 0.8"

"Enter the Hydr. Conductivity of Bottom LCR (cm/sec)-[
"WARNING!  Hydraulic Conductivity < 0.01 cm/second"
```

```
"The Geotextile Permittivity (/second)----------------:
"WARNING!  Permittivity of Geotextile > 0.5/second"
"WARNING!  Permittivity of Geotextile < 0.005/second"

"The Design Ratio (A Minimum of 50)-------------------:
"WARNING!  Design Ratio < 50"


3> Leachate Collection and Removal Systems Continued

"Enter the Apparent Opening Size of Geotextile (mm)--[
"WARNING!  Apparent Opening Size of Geotextile > 2 mm"
"WARNING!  Apparent Opening Size of Geotextile < 0.074 mm"

"Task Force Evaluation of Filter Criteria 22"
"  WARNING!  AOS of Geotextile < No. 50 sieve (O.297 mm)"
"  WARNING!  AOS of Geotextile < No. 30 sieve (0.59 mm)"
"  OK!  The Geotextile Has Adequate Soil Retention Capabilities"

"Carroll/Chen Evaluation of Filter Criteria"
"  The Carroll/Chen O95/D85 (A Maximum of 2)---------:
"  WARNING!  Carroll/Chen O95/D85 > 2"
"  OK!  The Geotextile Has Adequate Soil Retention Capabilities"
"  The Carroll/Chen O95/D15 (A Minimum of 2)---------:
"  WARNING!  Carroll/Chen O95/D15 < 2"
"  OK!  The Geotextile Has Adequate Soil Retention Capabilities"

"Giroud Prediction for Loss of Fines"
"  Is the Relative Density (Dr) of the Soil Loose (Dr<50%),"
"  Intermediate (50%<Dr>80%), or Dense (Dr>80%)?  L,I,or D? "
"  WARNING!  Coefficient of Uniformity < 1.0"
"  The Giroud Limit at a Loose Density---------------:
"  The Giroud Limit at Intermediate Density----------:
"  The Giroud Limit at a Dense Density---------------:
"  WARNING!  Giroud Predicts Excessive Loss of Fines"
"  OK!  The Geotextile Has Adequate Soil Retention Capabilities"

"The Gradient Ratio (A Maximum of 3)-----------------:
"WARNING!  Direct Measure of Clogging Potential > 30"
"WARNING!  Direct Measure of Clogging Potential < 0.1"
"WARNING!  Gradient Ratio > 3.0"

"Enter the Friction Angle--LCR to Waste (degrees)----[
"WARNING!  Friction Angle > 45 degrees"
"WARNING!  Friction Angle < 20 degrees"

"Enter the Friction Angle--LCR to FML (degrees)------[
"WARNING!  Friction Angle > 30 degrees"
"WARNING!  Friction Angle < 10 degrees"

"The Design Ratio (A Minimum of 3)-------------------:
"WARNING!  Design Ratio < 3"
```

```
"Enter the Transmissivity of the LCR (sq m/second)---[
"WARNING!  Transmissivity < 3E-5 square meters/second"

"Enter the Permeability of the Sub-Base (cm/second)--[
"WARNING!  Permeability > 0.01 cm/second"
"WARNING!  Permeability < 0.0001 cm/second"

"The Design Ratio (A Minimum of 1.5)----------------:
"WARNING!  Design Ratio < 1.5"

"Enter the Roadway Sub-Base Friction Angle (degrees)-[
"WARNING!  Friction Angle > 40 degrees"
"WARNING!  Friction Angle < 25 degrees"

"The Design Ratio at 10% Penetration (Minimum of 3)--:
"WARNING!  Design Ratio < 3"

"The Subgrade Cohesion (tons/square foot)-----------:
"WARNING!  Subgrade Cohesion > 5 tons/square foot"
"WARNING!  Subgrade Cohesion < 0.5 tons/square foot"

"Enter Poisson's Ratio for the Subgrade-------------[
"WARNING!  Poisson's Ratio > 0.45 degrees"
"WARNING!  Poisson's Ratio < 0.3 degrees"

"Enter the Compression Index of the Subgrade---------[
"WARNING!  Compression Index > 0.3"

"Enter the FML Strain at Yield (percent)-------------[
"WARNING!  Strain at Yield > 20 percent"
"WARNING!  Strain at Yield < 10 percent"

"The Design Ratio for Flexible Foundations (2 Min)---:
"WARNING!  Design Ratio < 2"

"Enter the Friction Angle--FML to Soil (degrees)-----[
"WARNING!  Friction Angle > 20 degrees"
"WARNING!  Friction Angle < 10 degrees"

"The Design Ratio for Rigid Foundations (2 Minimum)--:
"WARNING!  Design Ratio < 2"


5> Surface Water Collection and Removal Systems

"The Transmissivity (square meters/second)-----------:
"WARNING!  Transmissivity > 0.01 square meters/second"
"WARNING!  Transmissivity < 0.00001 square meters/second"

"The Design Ratio (A Minimum of 10)-----------------:
"WARNING!  Design Ratio < 10"

"Enter the Friction Angle--Soil to SWCR (degrees)----[
"WARNING!  Friction Angle > 45 degrees"
"WARNING!  Friction Angle < 30 degrees"
```

```
"Enter the Friction Angle--LCR to Waste (degrees)----[
"WARNING!  Friction Angle > 45 degrees"
"WARNING!  Friction Angle < 20 degrees"

"Enter the Friction Angle--LCR to FML (degrees)------[
"WARNING!  Friction Angle > 30 degrees"
"WARNING!  Friction Angle < 10 degrees"

"The Design Ratio (A Minimum of 3)-------------------:
"WARNING!  Design Ratio < 3"

"Enter the Friction Angle--SLCR to Soil (degrees)----[
"WARNING!  Friction Angle > 45 degrees"
"WARNING!  Friction Angle < 20 degrees"

"Enter the Friction Angle--SLCR to SFML (degrees)----[
"WARNING!  Friction Angle > 30 degrees"
"WARNING!  Friction Angle < 10 degrees"

"Enter the Friction Angle--SFML to Soil (degrees)----[
"WARNING!  Friction Angle > 30 degrees"
"WARNING!  Friction Angle < 10 degrees"

"The Design Ratio (2 or 5 Minimum Depending on Load)-:
"WARNING!  Design Ratio < 2"
"WARNING!  Design Ratio is between 2 and 5"

"The Design Ratio at Yield Strain (0.5 Minimum)------:
"WARNING!  Design Ratio < 0.5"

"The Design Ratio at Ultimate Strain (1.5 Minimum)---:
"WARNING!  Design Ratio < 1.5"


4> Ramp and Standpipe Considerations

"Enter the Friction Angle--Soil to LCR (degrees)-----[
"WARNING!  Friction Angle > 35 degrees"
"WARNING!  Friction Angle < 20 degrees"

"Enter the Friction Angle--Soil to FML (degrees)-----[
"WARNING!  Friction Angle > 22 degrees"
"WARNING!  Friction Angle < 14 degrees"

"Enter the Friction Angle--FML to LCR (degrees)------[
"WARNING!  Friction Angle > 18 degrees"
"WARNING!  Friction Angle < 10 degrees"

"The Static Design Ratio (A Minimum of 3)------------:
"WARNING!  Static Design Ratio < 3"

"The Dynamic Design Ratio (A Minimum of 2)-----------:
"WARNING!  Dynamic Design Ratio < 2"
```

```
"Enter the Friction Angle--SWCR to FMC (degrees)-----[
"WARNING!  Friction Angle > 40 degrees"
"WARNING!  Friction Angle < 10 degrees"

"Enter the Shear Strength of the SWCR (lbs/sq inch)--[
"WARNING!  Shear Strength > 100 pounds/square inch"
"WARNING!  Shear Strength < 10 pounds/square inch"

"The Design Ratio (A Minimum of 2)------------------:
"WARNING!  Design Ratio < 2"

"The Design Ratio (A Minimum of 5)------------------:
"WARNING!  Design Ratio < 5"

"Enter the Friction Angle--Soil to SWCR (degrees)----[
"WARNING!  Friction Angle > 45 degrees"
"WARNING!  Friction Angle < 30 degrees"

"Enter the Friction Angle--SWCR to FMC (degrees)-----[
"WARNING!  Friction Angle > 40 degrees"
"WARNING!  Friction Angle < 10 degrees"

"Enter the Tensile Strength of the SWCR (lbs/in)-----[
"WARNING!  Tensile Strength > 3000 pounds/inch"
"WARNING!  Tensile Strength < 500 pounds/inch"

"The Design Ratio (A Minimum of 5)------------------:
"WARNING!  Design Ratio < 5"

"Enter the FMC Strain at Yield (percent)-------------[
"WARNING!  Strain at Yield > 25 percent"
"WARNING!  Strain at Yield < 10 percent"

"The Design Ratio (A Minimum of 5)------------------:
"WARNING!  Design Ratio < 5"

"The Design Ratio Below Ground Level (1.1 Minimum)---:
"WARNING!  Design Ratio < 1.1"

"The Design Ratio at Ground Level (1.1 Minimum)------:
"WARNING!  Design Ratio < 1.1"

"The Design Ratio Above Ground Level (1.1 Minimum)---:
"WARNING!  Design Ratio < 1.1"
```